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Seasonal Change in Color of Spiders' Silk

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大崎　茂芳[1)]：クモの糸における色の季節的変化

Abstract: The optical properties of spiders' threads in different seasons were studied by optical reflectance in the range of wavelength from 400 to 700 nm. It was found that the color of threads from female spiders *Nephila clavata* collected in the same area changed seasonally from white or semitransparent in summer to yellow in autumn according to the seasonal change in the environment This change in color was concluded to be ascribed to the seretions from the mature female spiders *Nephila clavata* and to play an important role not only in protecting spiders from predators but also in capturing preys.

Introduction

The most characteristic feature of spiders is their ability to produce thread. Spider's thread has been studied mainly from morphological, mechanical and physico-chemical points of view (e.g. JACKSON, 1971; DENNY, 1976; WORK, 1976; FOELIX, 1982; GOSLINE *et al.*, 1984; WORK & MOROSOFF, 1982). However, the optical properties of spider's thread have not as yet been reported, probably because spiders' silk in orb-webs is usually less than 6 μm in diameter so that the observation or measurement of the color of such a silk and the quantitative evaluation of its optical properties have been quite difficult. Recently, the author developed an instrument which enabled him to collect a good deal of thread from spiders as a test sample, and had an opportunity to investigate the thermal properties in the previous papers (OSAKI, 1985; 1987; 1988) and the optical properties of spiders' silk.

In Japan, we have four seasons and the weather shows remarkable changes seasonally. In particular, in autumn, most leaves turn light brown. In general, animals and plants change their color seasonally. Thus, it is of interest to determine whether spiders at different stages of growing change the color of their thread seasonally.

The present study describes spectroscopic data obtained from spiders' threads in different seasons.

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Experimental

The sillk threads used in the present study were drag lines, which are very important for spiders to move, descend from trees, prey, and to make orb-webs (YAGINUMA, 1986). These drag lines were automatically wound around a rectangular frame 5 cm wide (see Fig. 1), using the instrument developed by the author. They were forcedly pulled out of spider bodies at a rate of about 20 cm/sec.

A large number of spiders were used; they were *Nephila clavata* L. KOCH, 1878 and *Yaginumia sia* (STRAND, 1906), which inhabit the suburb of Takarazuka City in Hyogo Prefecture in Japan from May to November, Spiders were collected in a short period less than a week in an area where the rate of growth is almost the same for the same species of spiders. The weight of female *Nephila clavata* increases from immature spiders in spring to mature spiders in autumn while that of male does not increase so much even in autumn. In autumn the weight of male *Nephila clavata* is smaller than that of female by an order of magnitude (OSAKI, 1987).

Visible rays ranging in wavelength from 400 to 700 nm were irradiated vertically to the sample placed on a MgO white standard board, and the optical reflectance was

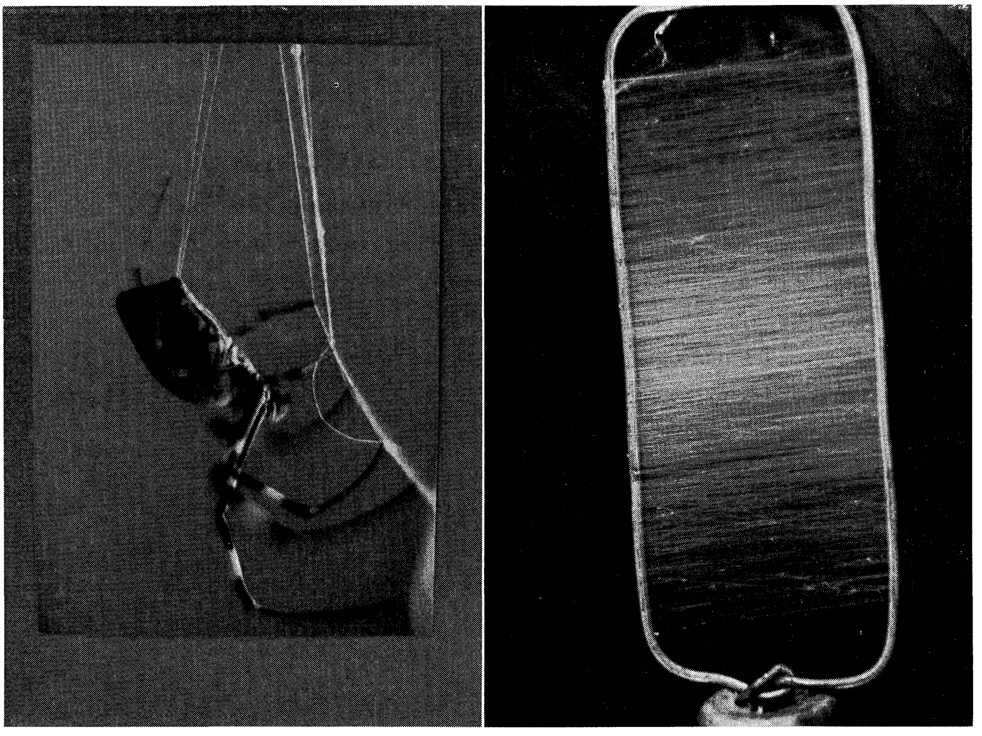

Fig. 1 Female *Nephila clavata* secreting drag line (left) and the drag lines forcedly pulled out of *Nephila clavata* and wound around a frame width ca. 5 cm width (right).

measured by use of a SPECTROPHOTOMETRIC COLORIMETER CMS-1200 manufactured by Murakami Color Research Laboratory, Japan.

The average densities of drag lines at 20°C were determined to be 1.13 g/cm^3 and 1.29 g/cm^3 for *Nephila clavata* in July and October, respectively, and 1.27 g/cm^3 for *Yaginumia sia* in September by flotation method with a mixture of benzene and chloroform.

Results and Discussion

Figure 2 shows the optical reflectance for drag lines of *Nephila clavata* collected in different seasons. The drag lines obtained in May to July (spiders being immature) show a uniform reflection or scattering in the range of wavelength from 400 to 700 nm, indicating that they are white or semitransparent. The drag lines collected from the end of August to September show a weak reflectance between 400 to 700 nm and those in October a very weak reflectance at about 450 nm. The latter suggests an existence of intense absorption at about 450 nm and implies that the drag lines from mature spiders in October are yellow as a complementary color of the absorption. In this way,

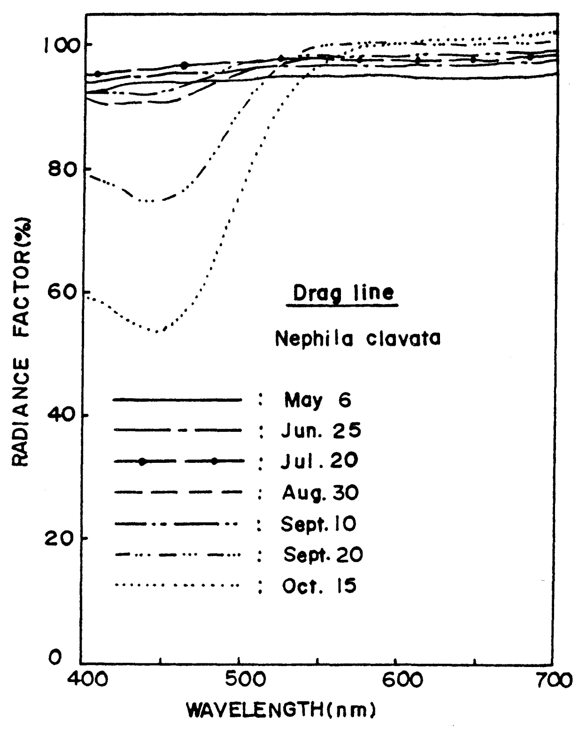

Fig. 2 Wavelength dependence of optical reflectance (radiance factor) for drag lines pulled out of *Nephila clavata* collected in different seasons and the same area.

we can quantitatively observe that the color of drag lines turns to yellow gradually as the autumn comes. We determined visually that the color of drag lines collected from female *Nephila clavata* in autumn was indeed yollow.

The reflectance spectra in Fig. 2 are illustrated in Fig. 3 by x, y and z chromaticity coordinates of spectrum in the CIE (Comission Internationale de l'Eclairage) XYZ color notation system. Here, the coordinates x, y and z[2] which almost corresond to the

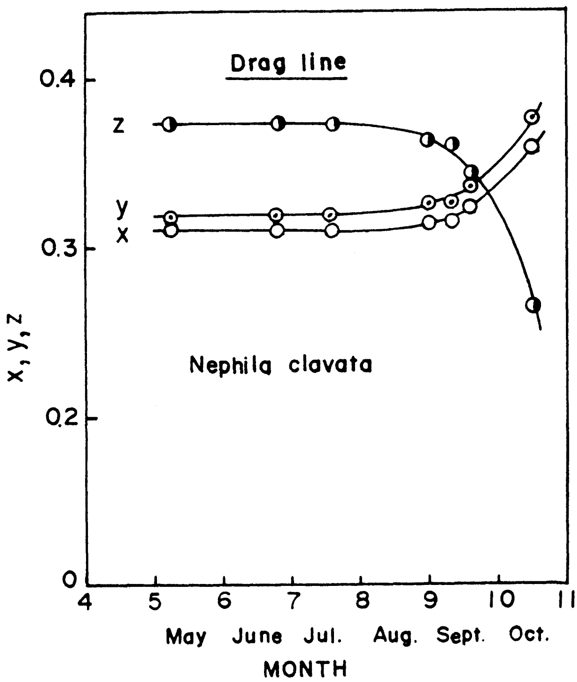

Fig. 3 x, y, z-color matching functions for drag lines of *Nephila clavata* collected in different seasons in CIE X, Y, Z color notation system. The numeral in the axis of abscissas represents the month. The color functions x, y, z show a main maximum at 600 nm for red, a maximum at 555 nm for green, and a maximum at 445 nm for blue, respectively. The x, y and z values represent the relative intensity of one of three primary colors of light.

2) The chromaticity coordinates x, y and z are defined as follows: $x \equiv X/(X+Y+Z)$, $y \equiv Y/(X+Y+Z)$, $z \equiv Z/(X+Y+Z)$ and $x+y+z=1$. The tristimulus value X, for example, is given by

$$X=100\int_{\lambda} P(\lambda)\, x(\lambda)\, \rho(\lambda)\, d\lambda \Big/ \int_{\lambda} P(\lambda)\, \rho(\lambda)\, d\lambda$$

where $P(\lambda)$ is the intensity of incident light with wavenumber λ and $\rho(\lambda)$ is the optical reflectance. The color matching functions x, y and z show a main maximum at 600 nm for red, a maximum at 555 nm for green, and a maximum at 445 nm for blue, respectively. As can be seen from their defining equations, the x, y and z values represent the relative intensity of one of three primary colors of light.

colors of red, green and blue, respectively, are expressed in terms of the spectral tristimulus values X, Y and Z in the XYZ system (STILES, 1987) instead of rgb (red-green-blue) system. The z chromaticity value stays almost constant till August and then decreases steeply. On the other hand, the x and y values begin to increase in September, and exceed the z value in the middle of September. These results clearly show that the color of drag lines of female *Nephila clavata* changes to yellow in autumn in Japan. We found that the drag lines collected from spiders in different seasons did not change their color even when they were kept at room temperature for three years.

From May or late spring to early summer in Japan, leaves are green; they are deep green in June, July and August (summer); faintly yellow in September (early autumn); and light brown in October (middle autumn). *Nephila clavata* born from an egg in May goes into the courtship in September or October. In November, the *Nephila clavata* female spider produces egg cocoon and then dies, while the male spider dies soon after mating.

The speckled body color of *Nephila clavata* changes from light green in August to yellow in September. This color change occurs concomitantly with that of leaves,

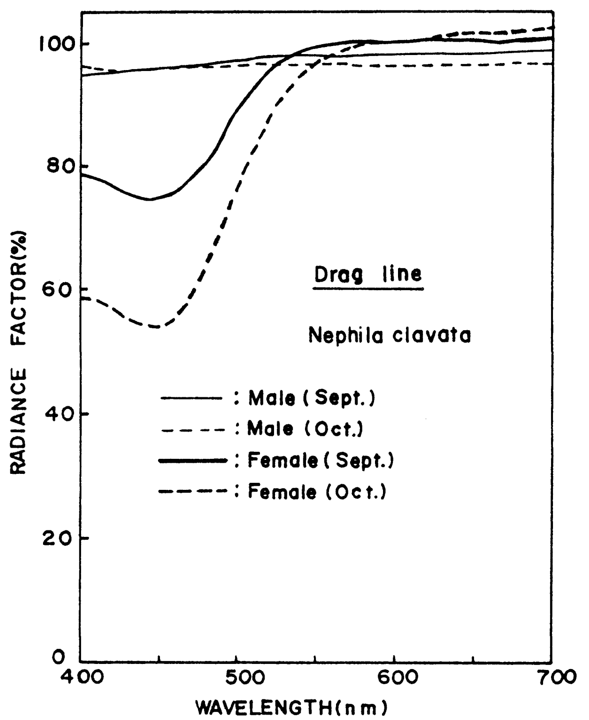

Fig. 4 Wavelength dependence of optical reflectance (radiance factor) for drag lines pulled out of male and female *Nephila clavata* collected in September and October.

suggesting that a spider living in the center of an orb-web protects itself with the inconspicuous color, light green or yellow. The change in the color of drag lines to yellow in autumn, found in this work, also suggests that spiders' threads may not be readily detected by predators and hence spiders can protect themselves against predators and can succeed in capturing their preys. White drag lines are conspicuous among brown leaves in autumn, but not among green leaves in summer. Therefore, they may need to change the color to yellow so as to be inconspicuous in autumn in terms of visibility to insects, predators and preys.

Orb-webs consisting of seven kinds of silken thread were also studied, but drag lines, one of their constituents, were used for the actual measurement since the orb-webs were too dirted by train, wind, etc. to be used.

The drag lines pulled out of a male spider of *Nephila clavata* in autumn do not change their color and are white or semitransparent, as can be seen from the data shown in Fig. 4. The *Nephila clavata* male makes no orb-web in autumn, but only the female does. Since the male goes in autumn to the orb-web of the female for courtship, it is unnecessary for him to build an orb-web for capturing insects and to produce

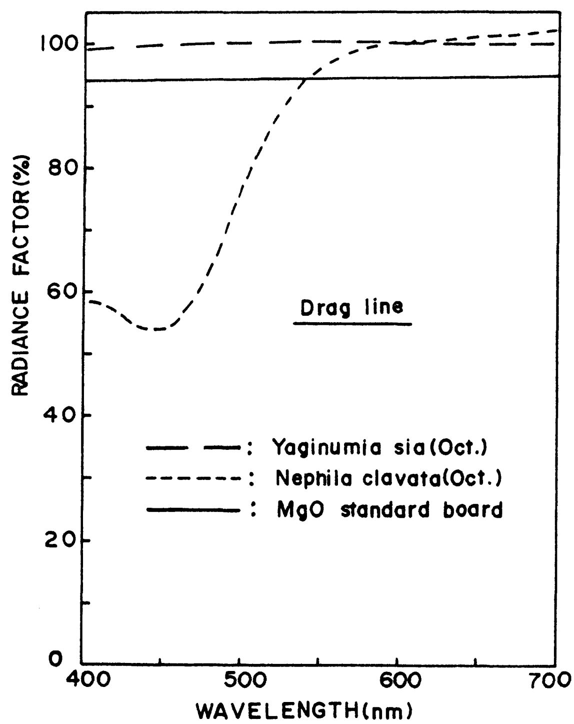

Fig. 5 Wavelength dependence of optical reflectance (radiance factor) for drag lines pulled out of *Yaginumia sia* and female *Nephila clavata* collected in October. MgO indicates a standard white board.

inconspicuous colored threads so as to match with environment. This may explain why the color of the male's drag lines does not change even in autumn.

On the other hand, the *Yaginumia sia* spider whose body color is brown builds an orb-web on the parapet at the river side in the evening, and captures preys only late in the evening. The color of its drag line does not change even in October (see Fig. 5). The *Yaginumia sia* spider may not need to change the color of the orb-web because insects may not detect this color in the evening and night; the colors of the bodies of the male *Nephila clavata* and *Yaginumia sia* are light brown in autumn.

As described above, the yellow color of drag lines of female spiders *Nephila clavata* in autumn may be explained by the seasonal change in the environmental color. As the other explanation for the yellow color in autumn, there is a possibility of secretion from the mature female spider *Nephila clavata*. When the female becomes mature, she may secrete a yellow secretion for attracting male spiders. However, such an explanation may be applied not to *Yaginumia sia* but to *Nephila clavata* spiders.

Conclusion

In summary, the change in color of female *Nephila clavata* spider's thread found in this work is in consonance with change in environment with seasons and may play an important role not only in protecting spiders from predators but also in capturing preys such as insects. On the other hand, the change in color into yellow in autumn is ascribed to the secretion from the mature female *Nephila clavata*. The secretion is considered to be an important substance for attracting male spiders.

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摘　　要

季節ごとに採取したクモの牽引糸の光学的反射特性を，400 nm から 700 nm の範囲で調べた。同一地域で採取されたメスのジョロウグモの牽引糸は，環境の季節的変化に伴って，夏には白色あるいは半透明色であるが，秋には黄色に変化することがわかった。秋における黄色化は，成熟したメスのジョロウグモによる分泌物に起因し，またクモ自らを捕食者から防衛するばかりでなく，餌を捕獲するために重要な役割を果たすであろうことが結論される。

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